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**A PORTABLE VITAL SIGNS
MONITOR FOR FIELD USE**

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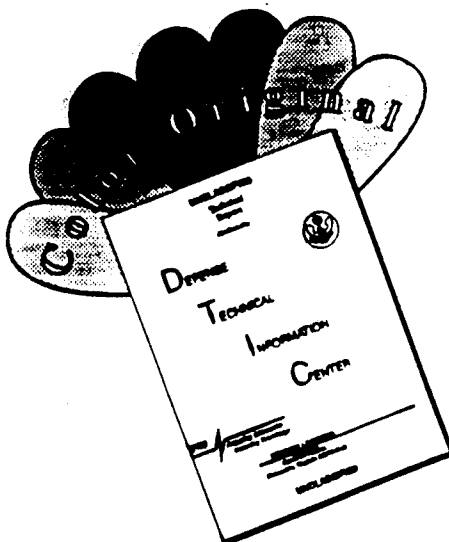


**Defence and Civil
INSTITUTE OF ENVIRONMENTAL MEDICINE
INSTITUT DE MEDECINE ENVIRONNEMENTALE
pour la défense**

1133 Sheppard Avenue West, PO Box 2000, North York, Ontario, Canada M3M 3B9
Tel. (416) 635-2000 Fax. (416) 635-2104

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**A PORTABLE VITAL SIGNS
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W. R. Dyck

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Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
North York, Ontario
Canada M3M 3B9

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A PORTABLE VITAL SIGNS MONITOR FOR FIELD USE

W. R. Dyck

EXECUTIVE SUMMARY

A Canadian Forces requirement exists for a portable, integrated system for monitoring the vital signs of patients in the field, under adverse, unconventional conditions. A vital signs monitor capable of monitoring heart rate, body temperature, and blood pressure in the field, is described in this report. The design has taken into account the need for future expansion, and ease in reprogramming the software, to reflect changing priorities with respect to which signs are to be monitored. A helicopter used in casualty evacuation, has been identified as a worst case condition for exposure to ambient noise, and preliminary trials have been successful in monitoring the three vital signs in this scenario. The device has also been used external to a modified chemical warfare casualty bag, to monitor the vital signs of a person sealed therein.

The device works well in response to laboratory-generated signals, but requires further evaluation on actual human subjects in the field, at various temperatures and humidities. In the case of blood pressure measurements, a clinical trial which would compare the measurements against an approved direct method, is also required to establish the reliability of this reading.

A PORTABLE VITAL SIGNS MONITOR FOR FIELD USE

TABLE OF CONTENTS

	ABSTRACT	ii
1.0	INTRODUCTION	1
2.0	DESIGN CRITERIA	2
3.0	DESCRIPTION OF THE HARDWARE	3
3.1	General	3
3.2	Heart Rate and Body Temperature Measurement	3
3.3	Blood Pressure Measurement	4
3.4	The Microcontroller and Display	5
3.5	Packaging and Power Supply	6
4.0	DESCRIPTION OF THE SOFTWARE	6
4.1	General	6
4.2	Heart Rate and Body Temperature Software Development	6
4.3	Blood Pressure Software Development	7
5.0	MONITORING USING THE VSM	7
6.0	TRIALS	9
6.1	Laboratory Trials	9
6.2	Helicopter Trials	9
7.0	RESULTS AND DISCUSSION	10
8.0	CONCLUSIONS AND RECOMMENDATIONS	12
	REFERENCES	13
	Figure 1: Vital Signs Monitor Circuit Diagram	14
	Figure 2: Vital Signs Monitor Shown with Sensors Attached	15
	Figure 3: External and Internal View of the Casualty Bag Interface	16
	Table 1: VSM Temperature Readings of a Constant Temperature (35°C) Water Bath	17
	Table 2: VSM Temperature Readings of a Constant Temperature (37°C) Water Bath	18
	Table 3: VSM Temperature Readings of a Constant Temperature (39°C) Water Bath	19

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ABSTRACT

A Canadian Forces requirement exists for a portable, integrated system for monitoring the vital signs of patients in the field, under adverse, unconventional conditions. A vital signs monitor capable of monitoring heart rate, body temperature, and blood pressure in the field, is described in this report. The design has taken into account the need for future expansion, and ease in reprogramming the software, to reflect changing priorities with respect to which signs are to be monitored. A helicopter used in casualty evacuation, has been identified as a worst case condition for exposure to ambient noise, and preliminary trials have been successful in monitoring the three vital signs in this scenario. The device has also been used external to a modified chemical warfare casualty bag, to monitor the vital signs of a person sealed therein.

1.0 INTRODUCTION

As early as 1973, as a consequence of Trial CHACE (Casualty Handling in A Chemical Environment), it was found that performing triage on patients wearing protective ensembles was difficult. Obtaining vital information, such as pulse rate and blood pressure, using standard issue instruments, could not be done without creating breaches in the casualty's protection. As a result of this capability deficiency, several devices have been developed [1,2,3] which monitor the heart rate of casualties in adverse environments, such as within casualty bags, without breaching the casualty's protection. Since one of the early design criteria was to measure signs without first compromising the casualty's protection, the first heart rate monitors (HRM) employed microphones to pick up and filter heart sounds through multi-layers of clothing. Concurrently, a blood pressure clamp (sphygmoclamp) was developed [4], which could adapt the cuff of any existing blood pressure monitoring device to an arm, from the outside of a casualty bag. Using the electronic stethoscope capability built into the HRM, also from outside the protection, blood pressures (auscultation method) were measured. This did, however, necessitate the use of three devices (blood pressure monitor, HRM, and sphygmoclamp) to measure one vital sign. Because the reliability of the heart rate readings of the HRM was lower than anticipated, they were not accepted.

It was not until the outbreak of hostilities in the Persian Gulf that the requirement for vital signs monitoring was reviewed. As a result, several compromises were made to the existing philosophy of monitoring vital signs. The two most important changes were, that the essential vital signs to be monitored were heart rate and body temperature (as opposed to heart rate and blood pressure), and that skin contact was allowed. The latter condition came from an extension from a current stated philosophy. The philosophy states that injured personnel in a CW environment, require decontamination, treatment, protection from further contamination, and external monitoring of their vital signs in a casualty bag and/or inside a helicopter. Decontamination infers clothing removal, and presents an opportunity for the placement of ECG electrodes, or temperature probes, or blood pressure cuffs.

A recent study determined that monitoring heart rate, body temperature and blood pressure, reliably and continuously, with one device, was feasible [5,6]. Many devices exist that measure heart rate and blood pressure, but those known to the author measure heart rate only while the blood pressure is being taken, i.e. not continuously. No commercially-available, portable device was found that could monitor heart rate, body temperature, and blood pressure simultaneously. This paper describes the development of a portable microcontroller-based vital signs monitor (VSM) for monitoring blood pressure as required in field scenarios, integrated with the capability of monitoring heart rate and body temperature continuously on casualties, even within a casualty bag.

2.0 DESIGN CRITERIA

During the development of the vital signs monitor (VSM), the following general factors were considered as design guidelines:

- a. rugged construction yet compact and light;
- b. long shelf life (minimum 10 years);
- c. be used by a medical assistant without extended training periods;
- d. must fit all male/female adults and be as non-invasive as practical;
- e. powered by batteries with an endurance of at least twelve hours;
- f. alarm functions must be audible (capable of being switched off), visual, and power loss sensitive;
- g. monitored parameters should be displayed digitally and be readable in dark or other adverse conditions;
- h. the power source must be isolated, eliminating the possibility of injury to the patient;
- j. employ reliable components;
- k. since this device will have wide application, many units will be required, therefore cost must be as low as possible (\$200 - \$400 range or lower); and
- m. environmental operating parameters consist of the following:
 - i. storage and operating temperature range -40°C to $+50^{\circ}\text{C}$,
 - ii. humidity operating range 0-95% R.H.,
 - iii. not effected by electromagnetic forces normally associated with aircraft or other machinery,
 - iv. stable in pressure reductions of up to 10,000 ft (523 mm Hg),
 - v. water resistant (waterproof desirable),
 - vi. unaffected by the usual chemicals and toxins that could be used in CB warfare, and
 - vii. the operation or connections of the monitor must not compromise the protection of a patient in a chemical and/or biological environment.

Currently, the VSM must be capable of measuring heart rates, body temperatures, and blood pressure. Heart rates should range from $15-240 \pm 1$ BPM (beats/minute). Alarms are required, should be adjustable and should have an initial hi/lo setting of 120/60 BPM. Averaged heart rate values are preferred in order to assess trends better. Body temperatures do not change rapidly; thus, a non-averaged display is sufficient. The range to be measured is $25-40 \pm 0.1^{\circ}\text{C}$. Alarm settings should also be adjustable, and have an initial hi/lo setting of $38.5^{\circ}\text{C}/34.0^{\circ}\text{C}$. In the event of transporting a hypothermic patient, it must be possible to reset the alarm, or turn it off. The range of blood pressures to be measured with the device should be 50-200 mm Hg, and the values, once acquired, should be displayed such that both systolic and diastolic pressures could be read simultaneously. Audible and

visual alarms for blood pressures are not required. If possible, the design of the device should also be flexible enough to adapt to changing priorities, i.e. be modified easily to measure other vital signs as deemed necessary in future scenarios.

3.0 DESCRIPTION OF THE HARDWARE

3.1 General

Because the vital signs monitor required by the CF should be capable of monitoring various vital signs (currently heart rate, body temperature and blood pressure), a programmable and expandable monitoring device which can be reprogrammed to meet medical requirements as required, is implied. This philosophy and many of the design targets lend themselves to a microcontroller technology to meet the objectives of this project. The programmability of the microcontroller not only allows for future expansion and/or modification of the capabilities of the device, but also drastically reduces the total component count, maintaining a portable and robust design.

3.2 Heart Rate and Body Temperature Measurement

To monitor heart rate accurately, reliably, and simply, measurement and conversion of ECG-like R-R wave intervals was chosen. Access to the bare chest during decontamination would provide the opportunity for attaching two ECG electrodes (HP adult disposable electrodes model 14445A) above and below the heart. To monitor body temperature, measurement and conversion of the output of a rectal thermometer, or thermister (Yellow Springs Instrument Co. Inc. Model 401 91A7207, or Baxter Healthcare Corp. 400 Series Rectal/Esophageal Probe) was chosen as the simplest (most reliable) and most commonly accepted method. Such a transducer could also be appropriately positioned during decontamination.

The sensors detect biological phenomena, and conditioning circuits either scale the voltages (heart rate) or convert the signals (body temperature) into appropriate voltage levels for use by a microcontroller. In the case of heart rate, the QRS component of an ECG wave was amplified, isolated (low pass filter), and subsequently converted into an electrical pulse (pulse shaper) compatible with microcontrollers. In the case of the body temperature, a microcontroller-controlled switch applies current to the thermister only when a reading is taken, eliminating the possibility of self-heating. The voltage across the thermister is measured, and the resistance-temperature relationship of the thermister is used to calculate the temperature. The microcontroller acquires and analyses the sensor signals, formats the measurements for the display, activates various alarms and performs various calibrations and diagnostic tests. The display receives the formatted data from the microcontroller and provides a readout of the vital signs and other information as required.

The heart rate and body temperature parts of the circuit diagram of the VSM (Fig 1) are, in fact, very similar to the ones reported previously [5]. A single input amplifier has replaced a more complicated differential design, resulting in a better tolerance of higher skin impedance. This reduces preparation (dermabrasion / alcohol swabbing) times previously required to reduce skin impedance. A new 'ECG level' circuit has been added to determine a background signal to give the controller a value, which a variable amplitude signal must exceed in order to be registered as a pulse. As mentioned above, the temperature measuring circuit has been modified to disable the thermister until a measurement is required. This was done for accuracy reasons. Previously, the resistance of the thermister and the transistor switch were added when the thermister was turned on, and the transistor resistance, although small, was unpredictable. The current circuit only looks at changes in the thermister resistance.

3.3 Blood Pressure Measurement

The oscillographic method of obtaining blood pressure was chosen, because it yields the most accurate determination of arterial pressures, is already widely used and accepted, is simple in design by using the cuff as the only transducer, and has the advantage of being adapted to various non-standard locations on the body. Compared with the method described in the introduction (Sphygmoclamp, etc.), using oscillography reduces the number of devices required for taking the blood pressure from three to one.

When considering the means of inflating and deflating the cuff, the semi-automatic method was selected over the automatic or manual methods. The semi-automatic method requires the operator to inflate the cuff manually, eliminating the need for a power-hungry, noisy, and expensive pump (automatic method). The pre-set pressure relief valve allows the cuff to deflate automatically, at a uniform, generally accepted rate ($\sim 2\text{-}4$ mmHg/second). During the deflation phase, cuff pressure measurements are made. This valve overcomes the subjectivity of the bleed rate inherent in the manual method.

The transducer used to measure cuff pressures was a Motorola MPX5050 pressure transducer, which has internal signal conditioning to give outputs particularly suited for microprocessor based systems. Its pressure range is given as $0\text{-}370$ mmHg $\pm 0.2\%$ full scale. It is temperature compensated, such that the maximum error over the full temperature range (-20°C to $+40^{\circ}\text{C}$) and pressure range, does not exceed 1.0% . It is also a low power device, such that at a supply voltage of 5.0 Vdc, the supply current is approximately 8.0 mAdc.

Basic signal conditioning was used to convert the raw output of the pressure transducer into signals compatible with the microcontroller. A standard blood pressure cuff, complete with inflating bulb and automatic-deflating valve assembly,

is connected to the pressure sensor. During a normal measurement of blood pressure, the sensor detects a sharp rise in cuff pressure (inflation phase), followed by a slowly decreasing ramp (deflation phase). Superimposed on the decreasing pressure ramp are the individual pulse pressure peaks of varying height which correspond to heart beats. Proper height measurement of these peaks is of critical importance because their amplitude is used as the basis of blood pressure determination. To separate the peaks from the decreasing ramp, the signal is filtered and amplified.

The software identifies the signal peak-to-peak heights. In order to make the best possible peak-to-peak measurements, the signal is centred in the microcontroller input range. Typically, the largest peak following the amplifier (Fig 1) is approximately 60% of the input range. Once the low and high points of the signal have been determined, the microcontroller sends out an appropriate DC offset signal to a level shifter, which biases the signal up or down so that it remains fully within the A/D input limits. As long as the peak-to-peak value is less than 5V, there will be no clipping. Also, once the peak has been validated, the microcontroller sends a separate signal to a yellow LED, as a visual confirmation that a valid peak has been detected.

As with the heart rate and body temperature conditioning circuits described above, the hardware (Fig 1) associated with blood pressure signals differs very little in concept to a previous model reported elsewhere [6]. The actual differences deal with the sophistication of the filter. During the helicopter trials described below, it was determined that the ambient cockpit frequencies (vibrations detected by the cuff, down to ~5 Hz) were very close to those contained in the blood pressure peaks. An eighth order Butterworth filter was added to the circuit, replacing first and second order filters which weren't able to separate the two signals adequately.

3.4 The Microcontroller and Display

The appropriate microcontroller and display for the VSM were selected on the basis of their power requirements. A low power Motorola 68HC805B6 makes up the central processing unit in the existing device. The display currently being used is 16 characters wide by 2 lines (enough space to display heart rate, body temperature, systolic and diastolic pressures simultaneously), and is backlit on demand. The lower operating temperature criterion of -40°C was compromised in the selection of the display, because an LED (light emitting diode) display meeting that criterion would require too much power. A low power LCD (liquid crystal display, Hantronix HDM-16216L-XCO) with an operating temperature of -20°C was considered adequate and required fewer batteries (size, weight and endurance consideration).

3.5 Packaging and Power Supply

The VSM (Fig 2) measures 80x160x60 mm, weighs approximately 625 g, and is packaged in ABS (acrylonitrile butadiene styrene) plastic i.e. exhibits high impact strength and flame retardency. The upper and lower halves are separated by a recessed polyurethane gasket for water and dust protection. The display is located on the face of the case, along with two push-button switches (on/off and reset) and two indicator lights (red = alarm, and yellow = valid pulse detected by the blood pressure software). All the components on the face are sealed via a black plastic mask, which also indicates, via units of measure, where each of the vital signs are displayed. Three water resistant connectors are located on the upper long side of the case. The two lead connector is for the rectal probe, the four lead connector is for the heart rate probe, and the hose connector is for one end of the blood pressure cuff. The electrical connectors are made of rubber and the normally-closed hose connector is made of polypropylene, for high chemical resistance and water tightness.

The electronics inside the case are powered by three 'C' sized batteries, currently mounted directly on the printed circuit board. The size and number were determined by the requirement of 12 hours continuous use, with intermittent display illumination. When the device is first turned on, the display is lit for approximately 1 min, and then turns off automatically. Pressing the reset switch, illuminates the display again. This was done to conserve power.

4.0 DESCRIPTION OF THE SOFTWARE

4.1 General

The software for measuring and displaying heart rate and body temperature [5] was developed separately from that measuring blood pressure [6]. The current VSM combined the two programs, with slight modifications such that all three signs could be measured and displayed simultaneously. The manner in which the software receives the conditioned vital signs signal levels, and uses them to determine heart rate, body temperature, and blood pressure, is changed very little from the previous developments and is summarised below. The program itself is too long to be included herein.

4.2 Heart Rate and Body Temperature Software Development

The microcontroller receives a pulse for every heart beat sensed by the conditioning circuit. This fact was used to write a program that calculates the time between each pulse and converts this value into a heart rate. The general method selected to determine the heart rate was to average the duration of 8 pulses and then determine how many pulses would be received in one minute.

An appropriate program was then developed to acquire the thermister voltage and convert it into a temperature. The two steps involved in measuring a temperature are, reading the thermister voltage on the appropriate A/D channel, and converting the digital equivalent of the voltage into a temperature. A low and high voltage reference are created on two pins on the microcontroller (pins 7 and 8 on Fig 1) which are used to define the operating temperature (voltage) range of the thermister output. The microcontroller segments this range into 256 equal voltage levels, each of which correspond to a unique word or temperature. Subsequently each analogue voltage level received from the thermister is then converted to a temperature using this lookup table.

4.3 Blood Pressure Software Development

As the cuff pressure decreases from a suprasystolic to a subdiastolic pressure, pulses of increasing, then decreasing amplitude are superimposed on the decreasing cuff pressure signal. The pressure where the greatest increase in pulse amplitude occurs corresponds to the systolic pressure, and the pressure where the greatest decrease in pulse amplitude occurs (after the maximum oscillations) is the diastolic pressure [7]. The mean arterial pressure corresponds to the lowest cuff pressure at which the maximum oscillations occur. A software method of digitally sampling pressure pulses, using a two dimensional filter for determining pulse validity, and establishing systolic and diastolic blood pressure via a 7-point averaging technique, was developed and is considered unique.

A peak height is calculated and compared to the previous peak height, and the difference is recorded as an increase or a decrease. The two dimensional filter was developed to increase the reliability of the readings by ignoring as many of the error peaks as feasible. It not only tests the peaks for amplitude but also for period, i.e. must be $\pm 40\%$ of the previous peak height and $\pm 25\%$ of the previous period between peaks, or it is rejected. Once legitimate pressure peaks have been identified, the increases and decreases are averaged with the three values before and after the current one. The pressure values where the new greatest increase and decrease occurred were determined to be the values closest to those predicted by theory.

5.0 MONITORING USING THE VSM

To monitor the heart rate of a casualty, two ECG electrodes are placed anywhere above and below the heart. The cable is connected to the electrodes, with the longer wire attached to the electrode below the heart. The other end of the cable is then connected to the monitor. The heart rate cable is actually a four wire cable, of which one pair is used for electrode connections. The other two wires are shorted. The presence or absence of the short circuit is monitored by the VSM to determine whether a heart rate cable is attached.

Any 400 series rectal/esophageal probe can be used to measure body temperature. The probe is inserted, and the other end, usually a mini-plug (Baxter), is connected to an adapter supplied with the device, and connected to the VSM. If the connector is a larger phono plug (Yellow Springs), a new adapter would have to be obtained.

When the device is turned on, the software version and battery capacity are displayed, with backlighting, for a short time, followed by a screen showing starting values of all the vital signs. An alarm may sound if starting values are outside the pre-set alarm levels. The display itself would then be the only way to determine which vital sign caused the alarm. The alarm can be reset by pressing the reset switch, but this would also reset the alarm window to the current value plus or minus a predetermined value at which a new alarm is sounded. For temperature, the new alarm window is $\pm 0.2^{\circ}\text{C}$, and for heart rate, the new window is ± 5 BPM.

A later development of the VSM included the development of the capability of monitoring a casualty inside a casualty bag via a bag interface. It was previously thought that leads connecting sensors to the monitor could be passed through a casualty bag where the zippers, which seal the bag, met. Observations were made that the opening created by this procedure was unpredictable, and therefore unacceptable. To overcome this deficiency, a bag interface (Fig 3) was developed, following a design [8] previously used in the Gulf War to allow cooling tubes to pass through a pilot's chemical protective ensemble, without compromising his protection. The interface was comprised of a row of four flanged tubing connectors RF-sealed to polyurethane coated nylon, and double-stitched to the casualty bag with a CW material patch on either side of the bag. A short length of two and four wire cable, with appropriate connectors at either end, was inserted through two of the ports, and sealed with silicone rubber sealant. Two equally short lengths of 0.125" ID tygon tubing were sealed into the other two ports. The appropriate male and female connectors were attached to the electrical cables and tygon tubing.

Once a casualty was placed inside a casualty bag, the ECG lead was connected to the four wire interface connector inside the bag. The adapter for the temperature probe was moved from the monitor to the inside of the bag, and the rectal probe was connected to the adapter. A blood pressure cuff was placed around the casualty's arm, and the two tubes from the cuff were connected to the two tygon tubes. The bag was then sealed, and vital signs were read as required from the outside of the bag by connecting the outward protruding interface leads to the vital signs monitor.

6.0 TRIALS

6.1 Laboratory Trials

The heart rate monitor portion of the VSM was tested using an oscilloscope and a function generator as an input. The frequencies were varied up and down within the range specified in the design. The device was also attached to several volunteers. Nine heart beats or eight R-R wave intervals were measured and averaged and compared to the VSM display.

The body temperature portion of the device was first tested with a variable resistor to confirm proper function over the normal operating range. Another trial consisted of connecting six different rectal probes (3 made by Baxter and 3 made by Yellow Springs) to each of six different monitors, and the temperature of a temperature-controlled water bath at three settings (35°C, 37°C, and 39°C) was monitored.

A digital oscilloscope (Philips PM3320A) was used to give a visual display of the pressure peaks appearing at the input to the microcontroller and many blood pressure measurements were taken of three individuals. Using the Erlanger method of determining systole and diastole [7], and assuming the cuff pressure determinations were accurate, blood pressure was determined on the oscilloscope and then compared to the monitor display. A second off-the-shelf blood pressure unit (sold for home use) was connected in parallel with the VSM, and again many blood pressures were determined and compared.

6.2 Helicopter Trials

In the final stages of the development of the blood pressure monitoring capability, it was decided to evaluate the performance of the VSM aboard a CF twin Huey helicopter. Three sorties were flown, each one of approximately one hour duration, where heart rates, body temperatures and blood pressures were measured on the ground with rotor spinning, hovering, and in flight simulating a casualty evacuation. During the first sortie, only the VSM was taken aboard and tested. During the second, a storage oscilloscope was also used to determine the cockpit noise in the helicopter as sensed by the blood pressure cuff, and on the third, a computer was used to determine how the VSM software was functioning.

7.0 RESULTS AND DISCUSSION

Several models of the VSM were produced for field trial purposes. Throughout this development stage, constant attention was focused on maintaining a low component count to lend ruggedness and compactness to the design. Readily available, high precision components were chosen for ease of maintenance and resupply, and low cost. However, low power consumption, long shelf life, and environmental (temperature, humidity, pressure) operating characteristics, were also considered in component and design selection. The resultant device is small (80x160x60 mm) and light (~625 g). The ABS plastic case is both watertight and chemical and shock resistant. With careful selection of components and design, the storage range of the VSM is predicted to be -40 to +70°C, and the operating range is predicted to be -20 to +50°C. The current average cost of materials to produce 10 devices is approximately \$250 each.

On the face of the case are two watertight buttons (on/off and reset) chosen large enough to be operated by personnel possibly wearing NBC gloves. The main purpose of the reset button is to cancel an alarm and reset the value of the vital sign which caused the alarm (heart rate or body temperature) to the new value within a smaller window (heart rate ± 5 BPM or temperature $\pm 0.2^\circ\text{C}$). Between the two buttons are two indicator LEDs; a red one to indicate an alarm, and a yellow one to confirm a valid pulse during blood pressure measurement. The display (2 lines with 16 characters/line) exhibits heart rate, body temperature, and systole and diastole simultaneously, and is backlit when the device is turned on or when the reset button is depressed. Backlighting remains on for approximately one minute and then shuts off to conserve power. The lower operating temperature criterion of -40°C was compromised in the selection of the display, because an LED display meeting that criterion would require too much power. An LCD display (low power) was chosen with an operating temperature of -20°C, which was considered adequate and required fewer batteries (size, weight and endurance consideration). Once the sensors are connected, operating the device using the two buttons requires no lengthy training.

Three 'C' cell batteries provide power to the device. This configuration was calculated to provide 12 hours of continuous operation at -20°C with the backlighting employed one minute out of every five. The condition of the batteries i.e. percent capacity remaining, is indicated on the display when the device is turned on. Using batteries, also, precludes any danger of the power source injuring the patient.

With respect to future expansion possibilities and the microcontroller configuration, there are only five out of eight A/D ports and twenty out of twenty-four I/O ports allocated thus far. The current software (heart rate, body temperature and blood pressure) takes up approximately 3.0 Kbytes out of the available 16 Kbytes

of on-board memory and less than half of the available 362 bytes of RAM.

The goals with respect to measurement ranges of the vital signs of interest have been met or exceeded. Heart rates of 15 to 240 BPM, and temperatures of 25 to 40°C have been met, and the blood pressure requirement of 50 to 200 mmHg has been exceeded i.e. 16 to 255 mmHg.

To determine the accuracy of the measurements of vital signs, laboratory tests were done. With respect to oscilloscope tests of heart rates, after rounding off the calculated rate values to the nearest integer value, the calculated and displayed rates were the same. This conforms to the requirement of being accurate to within 1 BPM. When the frequencies were changed, the display showed the correct rate after approximately 10 beats. This result confirms that the device is properly averaging 8 heart rate periods or nine heart beats. Tests were also conducted on several individuals, and also found to be accurate to within 1 BPM. Simulating a rectal probe with a resistor showed that the hardware and software were working as designed. The results of the constant temperature water bath trials are shown in Tables 1-3, and show that the readings taken were always within 0.1°C of the setting.

The results of the blood pressure tests showed that the displayed values and the rather subjective measurements made on the oscilloscope were within 5 mmHg of one another. When the two blood pressure units were connected in parallel, the two units were similar most of the time (within 10 mmHg of one another), but did occasionally differ by greater amounts. The off-the-shelf unit, on several occasions, failed to give any reading at all, displaying an error message to retry the procedure, while the VSM gave a reading in the expected range.

During the first helicopter trial, it was discovered that the heart rate and body temperatures were acquired and displayed without any problems. The determination of blood pressure, however, proved to be very difficult because of the high interference of the low frequency vibrations in the cockpit. These frequencies were not sufficiently filtered by the VSM. The second helicopter trial focused on the blood pressure capability only. The noise filtering of the device was improved, but with the help of a digital oscilloscope (with fast fourier transform capabilities), it was discovered that there was still an overlap of noise and measuring frequencies. An analog-only system of filtering was abandoned, and digital signal processing and filtering was invoked. Sharper filter frequency cut-offs were the result, and more reliable blood pressure readings were obtained during the third flight. It was also confirmed that the software was indeed determining systolic and diastolic blood pressures as predicted and designed, using a computer connected to the microcontroller via a temporary connection to its serial port.

In order to meet the requirement of being able to take measurements of a casualty within a casualty bag without causing any potential breach of the casualty's

protection, a modification to the casualty bag was developed. The bag was modified with the addition of an interface between the casualty and monitor, at about the waist area of the bag, towards the zipper/Velcro side. This would allow for easy hook-up of sensors and cables to the internal portion of the interface before closing the bag. The casualty bag modification has been tested on one individual in the lab, and no problems were encountered. Field trials have been organised at CFB Borden in the near future, to evaluate the VSM and the modifications to the casualty bag.

8.0 CONCLUSIONS AND RECOMMENDATIONS

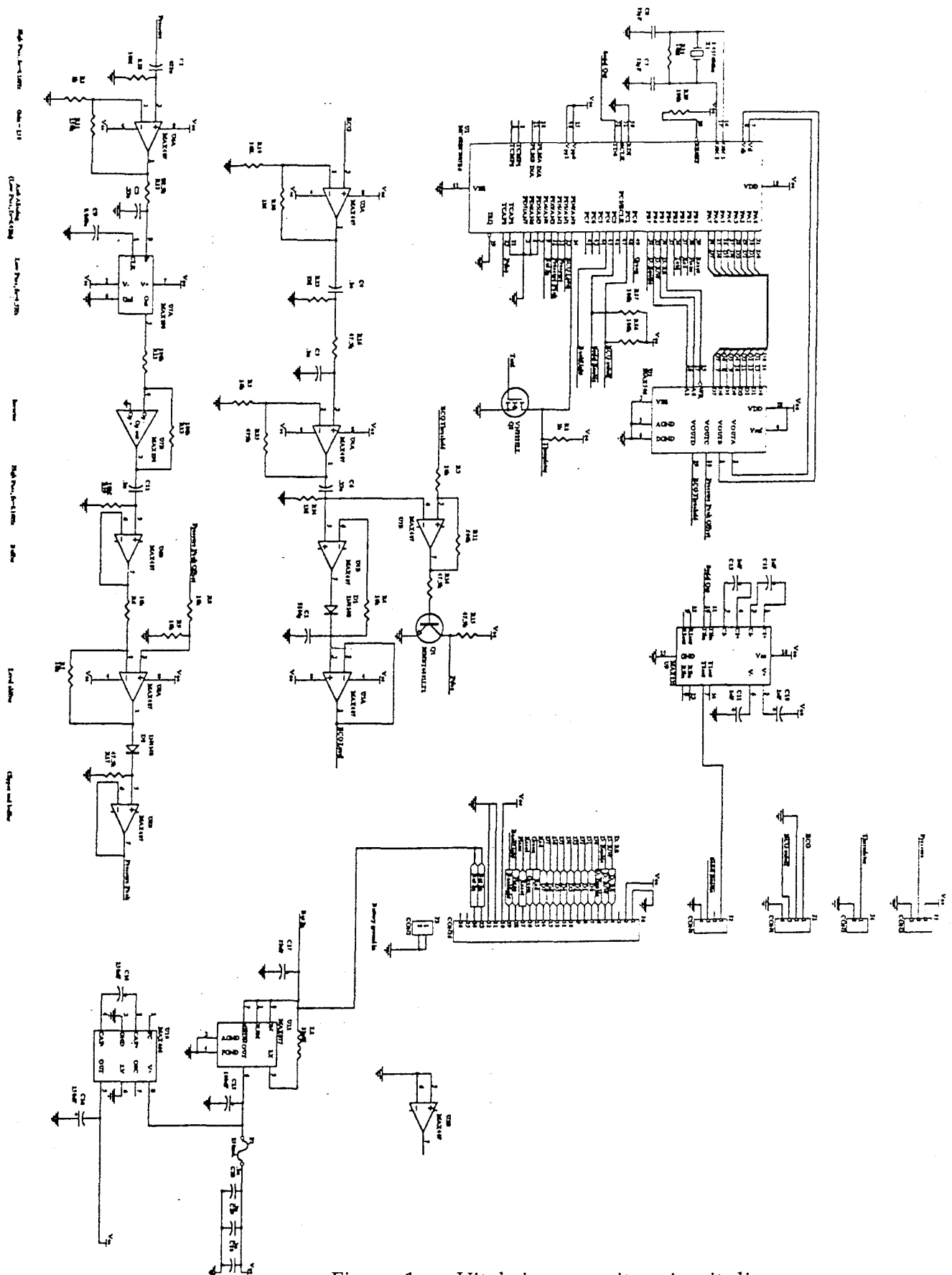
A vital signs monitor capable of monitoring heart rate, body temperature, and blood pressure in the field under adverse, unconventional conditions, is described. The design has taken into account the need for future expansion and software versatility to easily adapt to the changing needs of the medical services. The device works well in response to laboratory-generated signals, but requires further evaluation on actual human subjects in the field, at various temperatures and humidities. In the case of blood pressure measurements, a clinical trial which would compare the measurements against an approved direct method, is also required to establish the reliability of this reading.

Several noisy environments in which this device might be used, have been identified, e.g. helicopters and ambulances used in casualty evacuation. More studies are recommended to quantify the possible interference these environments might have on the device, and make modifications to the design or to the method of operation to lessen their effect. The integrity of the modifications to the casualty bag have also never been tested.

Once field trials and engineering development are complete, it is recommended that the VSM be adopted into the CF medical system, and be procured in sufficient quantity for use at home and abroad.

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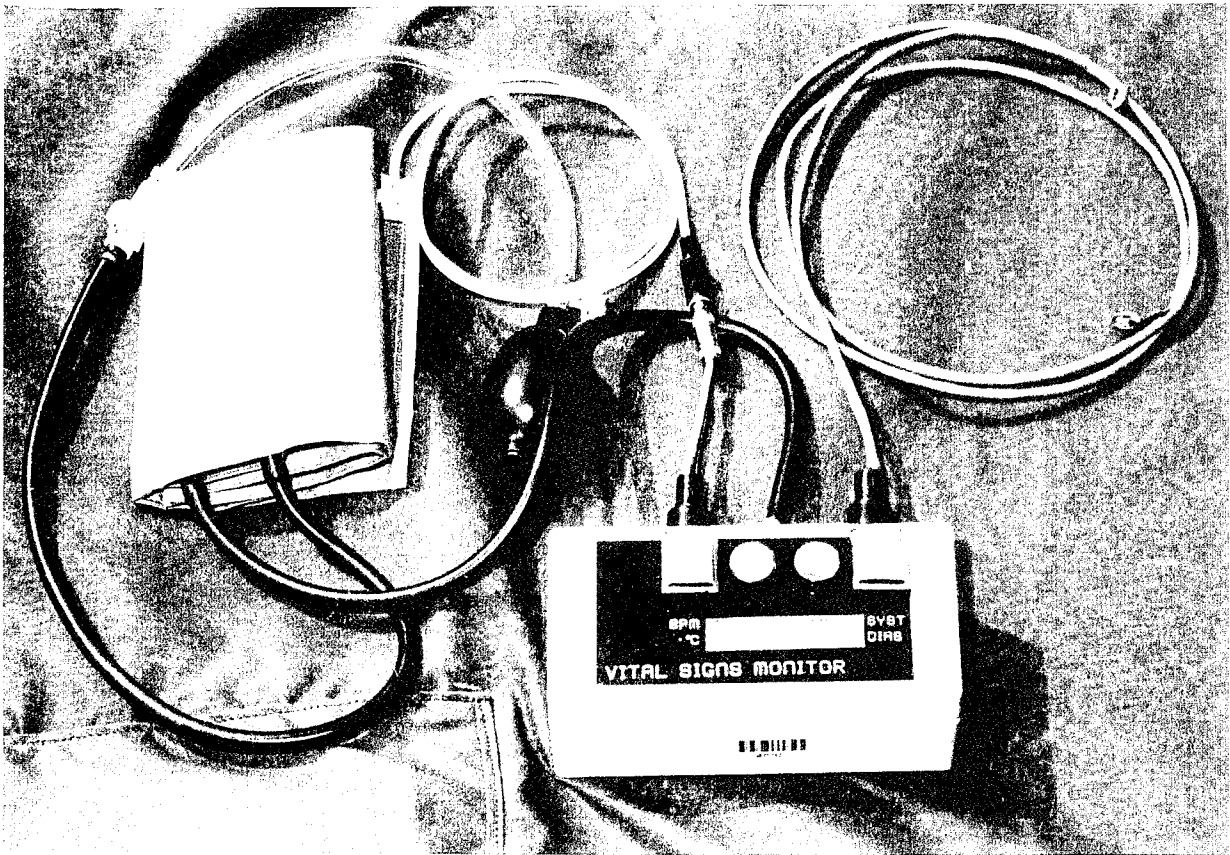


Figure 2: Vital signs monitor shown with sensors attached.

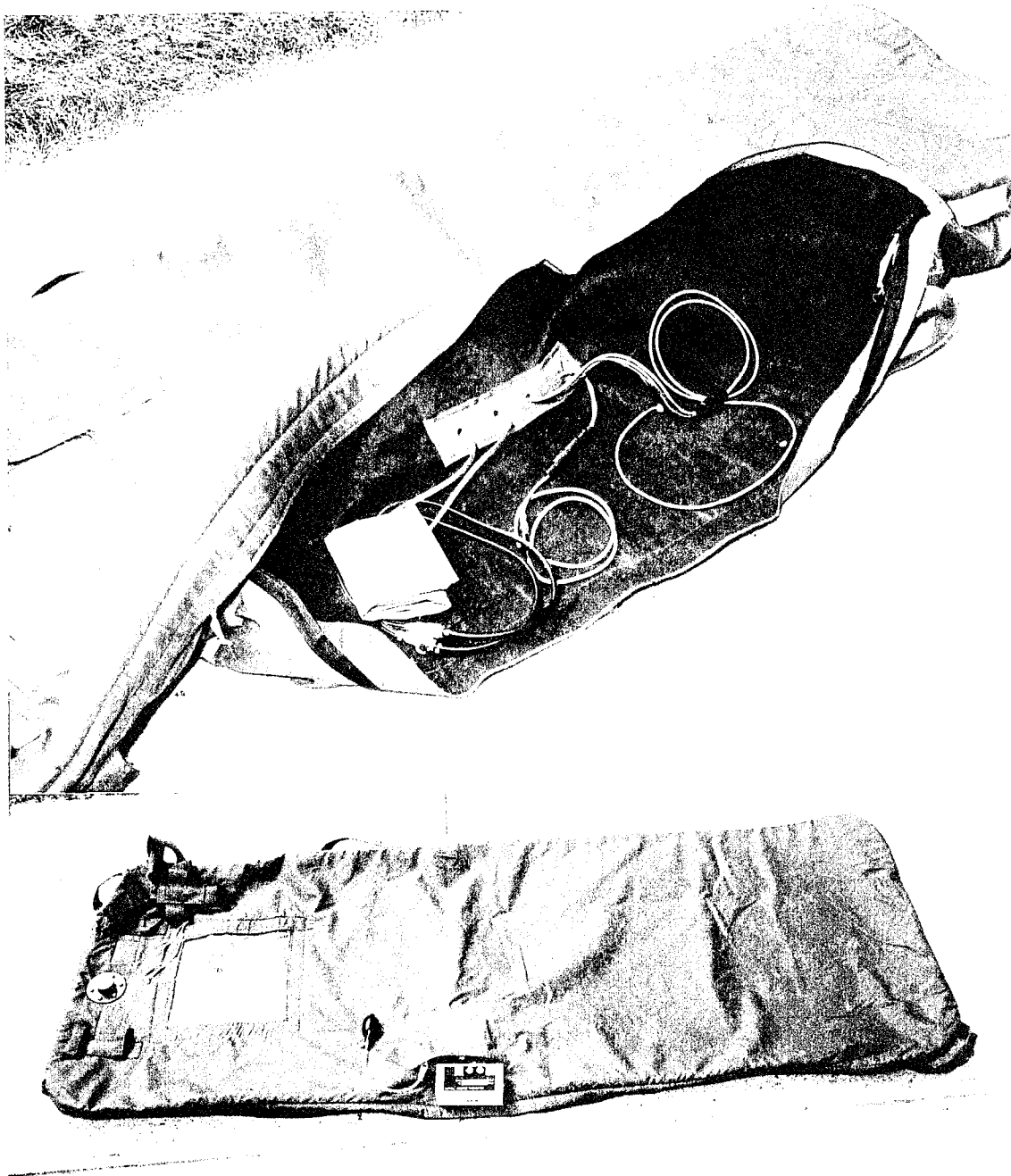


Figure 3: External and internal view of the casualty bag interface.

**Table 1: Vital Signs Monitor
Temperature Readings (°C) of a
Constant Temperature (35°C) Water Bath**

<i>VSM #</i>	<i>Rectal Thermometer</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
7596	35.0	35.1	35.0	35.0	35.0	35.1
7597	34.9	35.1	35.0	35.0	35.0	35.1
7598	34.9	35.1	35.0	35.0	35.0	35.1
7599	35.0	35.2 *	35.0	35.2 *	35.1	35.1
7600	35.0	35.1	35.0	35.0	35.0	35.1
7602	35.0	35.1	35.1	35.1	35.1	35.1

* Bath temperature set to 35 °C.
Bath reading = 35.1 °C.

**Table 2: Vital Signs Monitor
Temperature Readings (°C) of a
Constant Temperature (37°C) Water Bath**

VSM #	<i>Rectal Thermometer</i>					
	1	2	3	4	5	6
7596	37.0	37.1	36.9	37.1	37.0	37.1
7597	37.0	37.1	37.0	37.1	37.0	37.1
7598	37.0	37.1	37.0	37.1	37.0	37.1
7599	36.9	37.1	37.0	37.1	37.0	37.0
7600	37.0	37.1	36.9	37.0	37.0	37.1
7602	37.0	37.1	37.0	37.1	37.0	37.1

Bath temperature set to 37 °C.

**Table 3: Vital Signs Monitor
Temperature Readings (°C) of a
Constant Temperature (39°C) Water Bath**

VSM #	<i>Rectal Thermometer</i>					
	1	2	3	4	5	6
7596	39.0	39.1	39.0	39.1	38.9	39.1
7597	39.0	39.1	38.9	39.1	39.0	39.1
7598	39.0	39.1	38.9	39.1	39.0	39.1
7599	39.0	39.1	39.0	39.1	39.0	39.1
7600	38.9	39.1	38.9	39.1	39.0	39.1
7602	38.9	39.1	39.0	39.1	39.0	39.1

Bath temperature set to 39 °C.

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A Canadian Forces requirement exists for a portable, integrated field system for monitoring the vital signs of patients in the field, under adverse, unconventional conditions. A vital signs monitor capable of monitoring heart rate, body temperature, and blood pressure in the field, is described in this report. The design has taken into account the need for future expansion, and ease in reprogramming the software, to reflect changing priorities with respect to which signs are to be monitored. A helicopter used in casualty evacuation, has been identified as a worst case condition for exposure to ambient noise, and preliminary trials have been successful in monitoring the three vital signs in this scenario. The device has also been used external to a modified chemical warfare casualty bag, to monitor the vital signs of a person sealed therein.

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